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PRECISION STARAN CORRELATOR.(U)

JUN 77 T E GORSICA, L D STONER DAAK70-76-C-0247

UNCLASSIFIED GER-16464 ETL-0133 NL

1 OF 1

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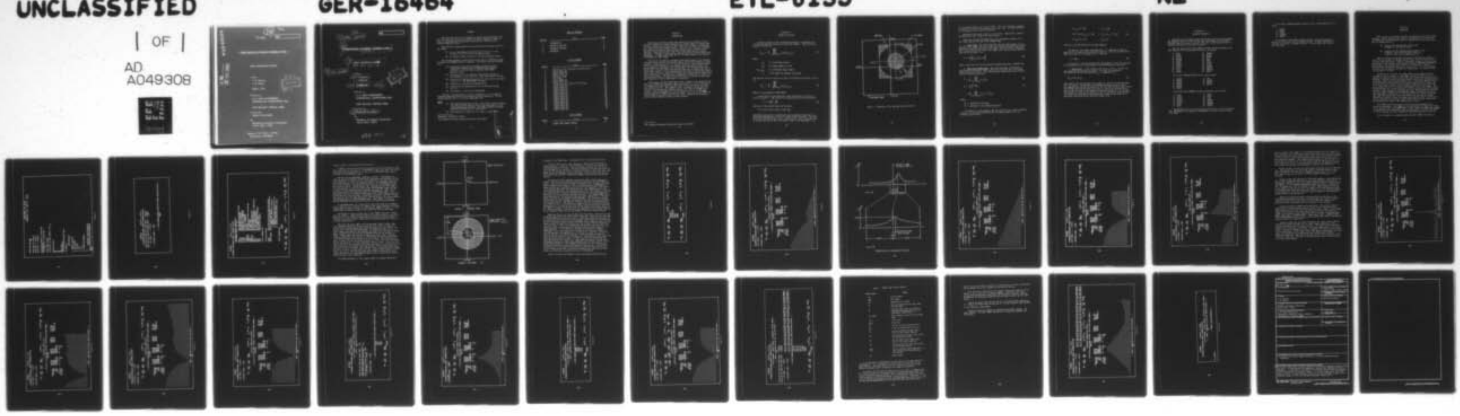

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# * PRECISION STARAN CORRELATOR *

FINAL TECHNICAL REPORT


Authors:

T. E. Gorsica

L. D. Stoner


JUNE 1, 1977



Prepared for:

U. S. ARMY ENGINEERING
TOPOGRAPHIC LABORATORIES (CSL)

FORT BELVOIR, VIRGINIA 22060

Contract No.

DAAK 70-76-C-0247

By:

Goodyear Aerospace Corporation
Akron, Ohio 44315

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(6) * PRECISION STARAN CORRELATOR. *

(9) FINAL TECHNICAL REPORT.

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# SUMMARY

This document describes the package of special-purpose computer software delivered and installed by Goodyear Aerospace Corporation (GAC) in the U. S. Army Engineering Topographic Laboratories (USA-ETL) under Contract DAAK70-76-C-0247.

This software package applies an area correlation function to two input images:

(1) A live image taken from flight tests of the U. S. Army Pershing II Missile Terminal Guidance System.

(2) A reference image for use with the above guidance system.

The software package has been operating at GAC on a HIS[a]/Xerox Sigma 9 computer and STARAN[b] parallel processor. The subject contract provided for:

(1) Conversion of all Sigma 9 assembly language code and unacceptable FORTRAN code to FORTRAN code acceptable to the E.T.L. Control Data Corporation (CDC) 6400 computer system.

(2) The conversion of all operator interactive portions of the package to run on the E.T.L. DIAL image analysis system.

(3) Conversion of appropriate sections of code to that applicable to the E.T.L. CDC 6400/STARAN interface.

(4) Preparation of engineering documentation.

(5) Installation and demonstration of the software package at E.T.L.

(6) Instructions in the use of the package.

The E.T.L. Project Monitor for this contract was A. T. Blackburn, Advanced Technology Branch of the Computer Science Laboratory. The GAC Project Engineer was T. E. Gorsica, Department 475.

**NOTES:**

(1) The Program Module Descriptions, Flow Charts, and the Program Listings were submitted as part of the requirements of the Program Documentation Report, GER-16465, Goodyear Aerospace Corporation, Akron, Ohio, 1 June 1977.

(2) The contractor's number for this report is GER-16464.

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[a]Honeywell Information Systems

[b]TM, Goodyear Aerospace Corporation, Akron, Ohio 44315

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## SECTION I

## INTRODUCTION

Correlation guidance systems that operate on the principle of automatically comparing a stored reference to a sensed image of a target area to determine position relative to the target offer a number of advantages over other available guidance systems. They are self contained, automatic, and accurate and require target location accuracy only relative to the immediate target area without requiring a high launch point-to-target accuracy. A number of such systems are being developed toward operational deployment. A common requirement for all of these systems is the need of a reference for each target.

The ability to support a guidance system operationally with suitable references could well be the deciding factor on the effectiveness of these systems. The data base will, in turn, be the key to the reference support. One of the major problems in the guidance reference support area is the establishment of requirements for a data base. The data base materials which have in the past been used would be expensive to prepare and use for operational support. Little consideration was given to operational requirements since the primary objective of these test programs was to demonstrate system performance. The data base requirements established for these test programs were overly stringent, and further work is required to determine what reduction in these requirements is practical.

The program provided establishes at ETL a capability of analyzing the effect of introducing reference image modification in terms of the resultant change which these modifications cause in the live versus reference correlation function. This capability was introduced through the transferral of an existing GAC[a] software system, the Precision STARAN[a] Correlator. The implementation of the correlator at ETL is for the RADar Aimpoint Guidance (RADAG)[a] system since there is an urgent requirement for a definition of the data base for this system. However, the procedures can be readily adapted to other guidance systems.

[a]TM, Goodyear Aerospace Corporation, Akron, Ohio 44315

## SECTION II

## METHOD OF SOLUTION

The basic purpose of the correlation program is to generate correlation and aperture functions of digitized imagery. The correlation function is given by:

$$\phi_{I,J} = \frac{1}{K} \sum_{i,j=-N,-N}^{N,N} L_{ij} M_{ij} R_{i+I,j+J} \tag{1}$$

where:

| | |
|---|---|
| $L_{ij}$ | is a live-image element |
| $M_{ij}$ | is a mask element (1 or 0) |
| $R_{i+I,j+J}$ | is a reference-image element |
| $K$ | is the number of elements correlated |

The aperture function required to obtain normalized correlation is given by:

$$A_{I,J} = \frac{C}{K} \sum_{i,j=-N,-N}^{N,N} M_{ij} R_{i+I,j+J} \tag{2}$$

where C is calculated as shown below.

A description of the subscripts used in Equation (1) and (2) is given in Figure 1. The value of K is obtained using the relationship

$$K = \pi(R_2^2 - R_1^2) \tag{3}$$

where $R_2$ is the outside radius of the mask,

$R_1$ is the inside radius of the mask.

Correlation and aperture calculations can be conducted along any row (generally meaning west to east) or column (south to north). The value of N can be selected from 1 to M. Excursions of I and J from zero are limited by the size of the live scene to that of the reference, i.e.,

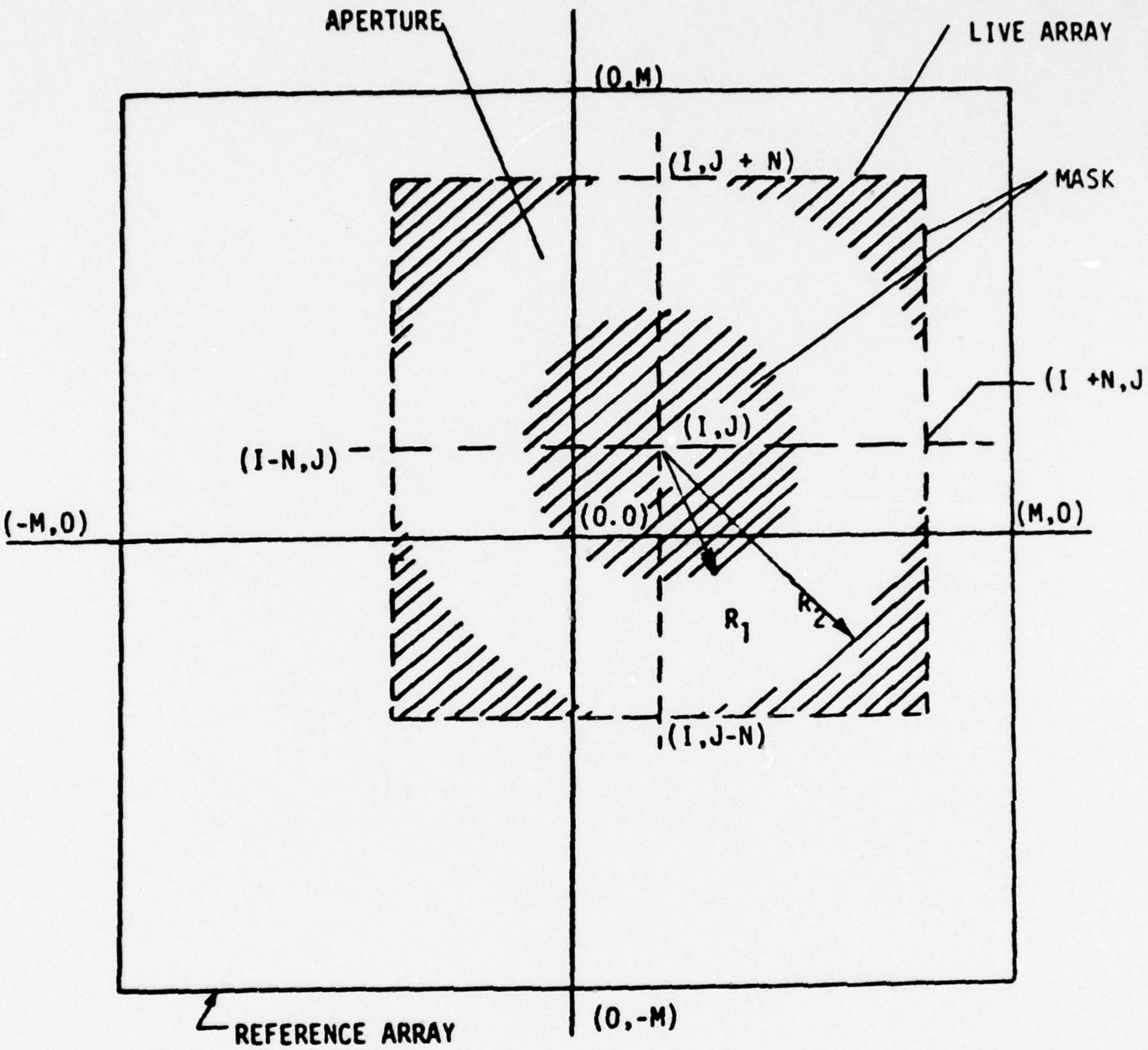



Figure 1. Reference, Live, and Mask Array Definition

I and J cannot exceed plus or minus (M-N). This limit produces a maximum of 2(M-N)+1 correlation and aperture values per line. The mask dimensions are selectable from the control terminal.

Computed values of $\phi_{I,J}$ and $A_{I,J}$ are printed. Additionally, control parameters and input-image titles are printed.

There are two modes of operation in the correlation program, viz., the linear mode and the non-linear (RADAG) mode.

a. Linear Mode - The linear mode uses the digitized imagery as it is received, i.e., image intensity values are retained throughout the process. Equations (1) and (2) are used in this mode. The value of C in Equation (2) is the maximum value of the live image within the correlation aperture (defined by the mask), i.e.,

$$C = \text{Max}\left\{ L_{ij} \mid L_{ij} \varepsilon\ L \cdot M \right\} \tag{4}$$

where L and M are the live and aperture (masked) data sets, respectively.

b. Non-Linear (RADAG) Mode - The non-linear mode of operation is programmed to simulate an adaptive AGC video processor and a non-linear sample weighting process. The video processor measurements are simulated with the following equations:

$$\bar{L} = \frac{1}{K} \sum_{i,j=-N,-N}^{N,N} L_{ij}\, M_{ij} \tag{5}$$

$$\tilde{\sigma} = \overline{\left| L_{ij} - \bar{L} \right|} \tag{6}$$

$$= \frac{1}{K} \sum_{i,j=-N,-N}^{N,N} \left| L_{ij} - \bar{L} \right| M_{ij}$$

where:

$\bar{L}$ = average of live scene

$\tilde{\sigma}$ = estimate of the standard deviation

The effect of video processor AGC and the non-linear sample weighting process is simulated by modifying the live-image elements with the following set of rules:

$$\text{IF } L_{ij} > \bar{L} + 2\tilde{\sigma} \quad , \quad L'_{ij} = 2\lambda\tilde{\sigma}$$

$$\text{IF } \bar{L} - 2\sigma \leq L_{ij} \leq L + 2\tilde{\sigma} \quad , \quad L'_{ij} = L_{ij} - \bar{L} + 2\tilde{\sigma} \tag{7}$$

$$\text{IF } L_{ij} < \bar{L} - 2\tilde{\sigma} \quad , \quad L'_{ij} = 0$$

where $L'_{ij}$ are the modified live image elements.

The modified live image, described by $L'$, is subsequently used in Equation (1) to compute the correlation function. Also, in the non-linear mode, the value of C in Equation (2) is given by:

$$C = 2\lambda\tilde{\sigma} \; . \tag{8}$$

This factor causes the quotient $\phi/A$, designated $\psi$ in the next section, to be proportional to the percentage of data correlating at any point.

c. <u>Output Data</u> - A plot program uses the $\phi_{I,J}$ and $A_{I,J}$ values from the output of the correlation program. For each line processed, the normalized correlation function $\psi_{I,J}$ is computed using

$$\psi_{I,J} = \phi_{I,J}/A_{I,J} \quad , \tag{9}$$

Additionally, the derivatives of $\psi$, namely, $\psi'$ and $\psi''$ are computed along the line chosen. The averages and standard deviations of $\phi$, A, and $\psi$, are computed and printed out along with the live and reference image titles. The maximum and minimum values of $\phi$, A, $\psi$, $\psi'$ and $\psi''$ are printed out as well as the positions of the maximum and minimum values of $\psi$, $\psi'$, and $\psi''$. Additionally, a three-point parabolic curve fit program has been provided to predict the locations of the maximum and minimum values of $\psi$ with a positional resolution better than one integer pixel.

## SECTION III

## RESOURCES REQUIRED

The GYPSC program opeates under the ETL/DIAL interactive environment. The FORTRAN program utilizes the CDC 6400, GAC STARAN, and PDP/COMTAL/TEKSCOPE computer systems in concert with their established ETL facility hardware and software interface subsystems.

The user application program GYPSC includes the MAIN program of the same name and its 21 associated subroutines as follows:

| | | | |
|---|---|---|---|
| 1. | GYPSC | 12. | CORRELV |
| 2. | YESNO | 13. | FETCH |
| 3. | GETINP | 14. | GETREF |
| 4. | DECODE | 15. | SWAP |
| 5. | BIGTOP | 16. | TURN |
| 6. | OMENU | 17. | SKIPR |
| 7. | TEKOUT | 18. | LIVBLD |
| 8. | GETSCN | 19. | IRADAG |
| 9. | STAT | 20. | RADAGF |
| 10. | PLOTR | 21. | APERTUR |
| 11. | CORREL | 22. | APSET |

First-level FORTRAN/SYSTEM/library calls include:

| | | | |
|---|---|---|---|
| 1. | CLOSMS | 7. | EOR |
| 2. | READMS | 8. | OPENMS |
| 3. | MOVLEV | 9. | REWIND |
| 4. | READEC | 10. | WRITMS |
| 5. | WRITEC | | |
| 6. | ENCODE | | |

First-level DIAL-FORTRAN interface subroutine calls include:

| | | | |
|---|---|---|---|
| 1. | FINIS | 8. | DREAD |
| 2. | LBLRD | 9. | FIND |
| 3. | LOCATE | 10. | GSET |
| 4. | PMINIT | 11. | IMGDSK |
| 5. | TEKMSG | 12. | LBLEXT |
| 6. | TITLE | 13. | SETCORE |
| 7. | UNPKI | 14. | TEKRD |

The Q9PFMGR routine is also called at first-level to link the permanent LUN (Logical Unit Number) F:94 FORTRAN file which stores the menu file, MENU.

First-level STARAN-INTERFACE software (refer to GER-16352) calls include:

1. SCNTRL
2. RCNTRL
3. STATUS
4. LOADPRG
5. DETACH

As configured, the GYPSC program requires a CM (central memory) execution field length (FL) of 106,000 (octal). The ECS (extended core storage) requirement is 36,864 (decimal). Two (2) COMTAL CRT display units are used.

## SECTION IV

## OPERATION

GYPSC is run as an operator interactive program from the DIAL system terminal. Before loging on the terminal, the operator must insure that the STARAN and the CDC 6400 are ready for communication with one another. This is accomplished by:

(1) Turning "ON" CDC peripheral device #31 (STARAN) via the CDC E display;

(2) Invoking the CDC communications program in the STARAN by typing "BA CDCIO (CR)" after the $ (dollar sign) on the STARAN decwriter.

GYPSC is resident on the CDC disk memory as an absolute program. It runs in a field length of 106,000 (octal) words, less than half of the available CDC core memory. GYPSC is accessed by loging on to DIAL in the normal way, selecting major projects sub-element 6 (PROGRAM DEVELOPMENT), and typing in the program name, "GYPSC", as illustrated in Figure 2. Should GYPSC no longer be resident on the CDC disk, it is only necessary to submit the CDC program card deck for compilation. All control cards are included in the deck.

GYPSC asks for the DIAL file image names of two images to be correlated, as shown in Figure 3. Note that figures referenced in this section are reproductions of actual GYPSC runs taken from the DIAL system TEKSCOPE. Operator entries have been underlined on these reproductions to distinguish them from program generated text. Should the operator enter a non-existent image name, he will be notified and GYPSC will again ask for a valid name. (Should a CR be entered instead of a valid name, the DIAL system software will present a catalogue of valid DIAL images. The system software will return to GYPSC if a CR is entered into the catalogue program.) When the two valid entries are made, GYPSC responds by placing the LIVE image on COMTAL A, the REFERENCE image on COMTAL B, displaying the image header information (if any) and asking for further directives. Note that the images used, GYLIVE and GYREF, did not have any header information (Figure 21 shows two images that contain header information). GYLIVE and GYREF are identical images except that the pixel intensities are reversed (one image is the negative of the other).

The "MENU" directive calls up a listing of the parameters and directives available. The "SUMM" directive displays the current settings of all of the GYPSC input PARAMETERS. Figure 4 shows the MENU and a SUMMARY of the default input parameters which are the values in effect when GYPSC is first accessed, and until changed by subsequent operator directives.

The run number is incremented each time the "START" directive is

```
                                        WELCOME TO DIAL
                                   VERSION 1.2, NOV 4, 1976
ENTER USER CODE [redacted]

ENTER USER ID (ET74545)

ENTER SETN[illegible] (DIALSET)

ENTER PACK [illegible]N (PK0015)

WAITING FOR OPERATOR TO MOUNT PACK
PACK MOUNTED
AVAILABLE CONTAL DISPLAYS ARE
      A B

ENTER CONTAL DISPLAY

DO YOU WANT TO ERASE CONTALS? (Y/N) Y

RESETING CONTALS
A1
A2
A3
B1
B2
B3
RESET DONE
LOGON COMPLETE
HIT CR FOR MAJOR PROJECTS MENU

PM COMPLETE

        MAJOR PROJECTS

1. GENERAL FUNCTIONS

2. DMA RESEARCH

3. PERSHING

4. ASPO

5. AQ II

6. PROGRAM DEVELOPMENT

6
        PROGRAM DEVELOPMENT
TYPE IN FUNCTION NAME AND PARAMETERS
GYPSC
```

Figure 2

```
GYPSC          04/28/77  11.02.49.
STARAN/CDC6400 AREA CORRELATION
ENTER DATA SET NAME FOR $LIVE$ IMAGE.   @ GYLIVE
ENTER DATA SET NAME FOR $REFR$ IMAGE.   @ GYREF
.....LIVE IMAGE..........GYLIVE

.....REFERENCE IMAGE.....GYREF

          .....ENTER PARAMETERS AND DIRECTIVES-($MENU$ FOR MENU LISTING).....
                          $MENU
```

Figure 3

```
GYPSC          04/20/77  11.04.15.
STARAN/CDC6400 AREA CORRELATION

            CORRELATION PROGRAM COMMAND MENU.
            THE COMMANDS ARE OF THE FORM

            MENU          CALL THIS MENU UP ON OUTPUT DEVICE
            R1=ZZZ        INNER RADIUS OF APERTURE
            R2=ZZZ        OUTER RADIUS OF APERTURE
            RX=ZZZ        REFERENCE DATA X COORDINATE
            RY=ZZZ        REFERENCE DATA Y COORDINATE
            LX=ZZZ        LIVE DATA X COORDINATE
            LY=ZZZ        LIVE DATA Y COORDINATE
            LINES=ZZZ     LINE COUNT
            LAMBDA=ZZZ    LAMBDA FACTOR FOR RADAG CALCULATIONS
            LINEAR        SET LINEAR MODE
            RADAG         SET RADAG MODE
            HORIZONTAL    HORIZONTAL CORRELATION ONLY
            VERTICAL      VERTICAL CORRELATION ONLY
            BOTH          BOTH VERTICAL AND HORIZONTAL CORRELATIONS
            CROSS         SET CROSS CORRELATION MODE
            AUTO          SET AUTO CORRELATION MODE
            SUMM          WRITE CURRENT PARAMETER SUMMARY
            START         BEGIN CORRELATION(S)
            DONE          FINISHED, EXIT PROGRAM

            END OF COMMAND MENU

            STATISTICS ENTRIES

            WIDTH         HALF WIDTH OF STATISTICS AND PLOT WINDOW
            OFFSET        OFFSET OF WINDOW CENTER FROM REFERENCE ORIGIN
            CURVE NUMBER  TYPE OF CURVE TO BE PLOTTED
                              1  UNNORMALIZED CORRELATION FUNCTION
                              2  APERTURE
                              3  NORMALIZED CORRELATION FUNCTION (PSI)
                              4  DYNAMIC MATCH CURVE (DPSI)
                              5  SECOND DERIVATIVE FUNCTION (DDPSI)

            ENTER COMMANDS HERE

                      *SUMM

 RUN  TYPE   AXIS  MODE        X -REFR- Y    X -LIVE- Y    R1 -APR- R2   SIZE  LAMBDA
   0  CROSS  HORI  LINEAR      0        0    0        0    0       150   150        2
                         *
```

Figure 4

entered to begin the designated correlation(s).

A "CROSS" correlation performs an area correlation of a subset of the LIVE image against the whole of the REFERENCE image. An "AUTO" correlation performs an area correlation of a subset of the REFERENCE image against the whole of the REFERENCE image.

The axis may be HORIZONTAL, VERTICAL, or BOTH. A HORIZONTAL correlation selects a doughnut shaped patch (designated the aperture) of the LIVE image with its center at $L_x, L_y$ and performs an area correlation of this patch against all of the possible areas of the REFERENCE image that fall on a horizontal line passing through $R_x, R_y$ on the REFERENCE image. See Figures 5 and 6. Stated another way, the patch of the LIVE image is slid horizontally a pixel at-a-time across the REFERENCE image from west to east. At each possible place the patch from the LIVE image is area correlated against the underlying area of the REFERENCE image. This generates a curve of correlation amplitude versus the horizontal position of the patch of the LIVE image. A VERTICAL correlation similarly slides the patch of the LIVE image vertically from the south to the north passing through point $R_x, R_y$ on the REFERENCE image. When "BOTH" is entered, both a HORIZONTAL and VERTICAL correlation are successively performed.

In the RADAG mode, the intensities of the LIVE image are re-mapped by an algorithm that simulates the adaptive AGC video processor and a non-linear sample weighting process in the hardware RADAG correlator. In the LINEAR mode, no change is made to the intensities of the LIVE image.

The number of lines of video sent to the STARAN processor is determined by "LINES". LINES should be equal to or greater than $R_2$, lest the edges of the round doughnut shaped aperture become flattened. However, if LINES is set to an overly large value, the program execution time will increase unnecessarily.

When the LIVE image comes from the guidance system's radar, (the usual operating mode), $R_1$ can be set to the inner radius of the scene content (the minimum-ground-range features picked up by the radar). $R_2$ can be set to the maximum ground range. All magnetic tapes of live radar imagery generated on the Goodyear Aerospace radar re-sampler system have a property that can be used to automatically set the aperture in GYPSC. These tapes have each pixel coded as an 8-bit byte. When the resampler determines that a pixel is not between the minimum and maximum radar ground range, the pixel value is set to zero. When the value of $R_2 - R_1$ is equal to 150, the GYPSC program will treat a live pixel as being within the aperture if it has a non-zero intensity value. This lets the scene content of the resampled live image accurately set the aperture size. This also implies that there should be no zero valued pixels within the aperture of the live images. As a special case, if the difference between $R_2$ and $R_1$ is equal to 150, GYPSC will use a square shaped aperture of 301 pixels on a side. This may be found useful when correlating full area images not pertinent to the RADAG guidance system. Otherwise $R_1$ and $R_2$ prescribe the circular aperture.

The lambda parameter is the integer number of standard deviations

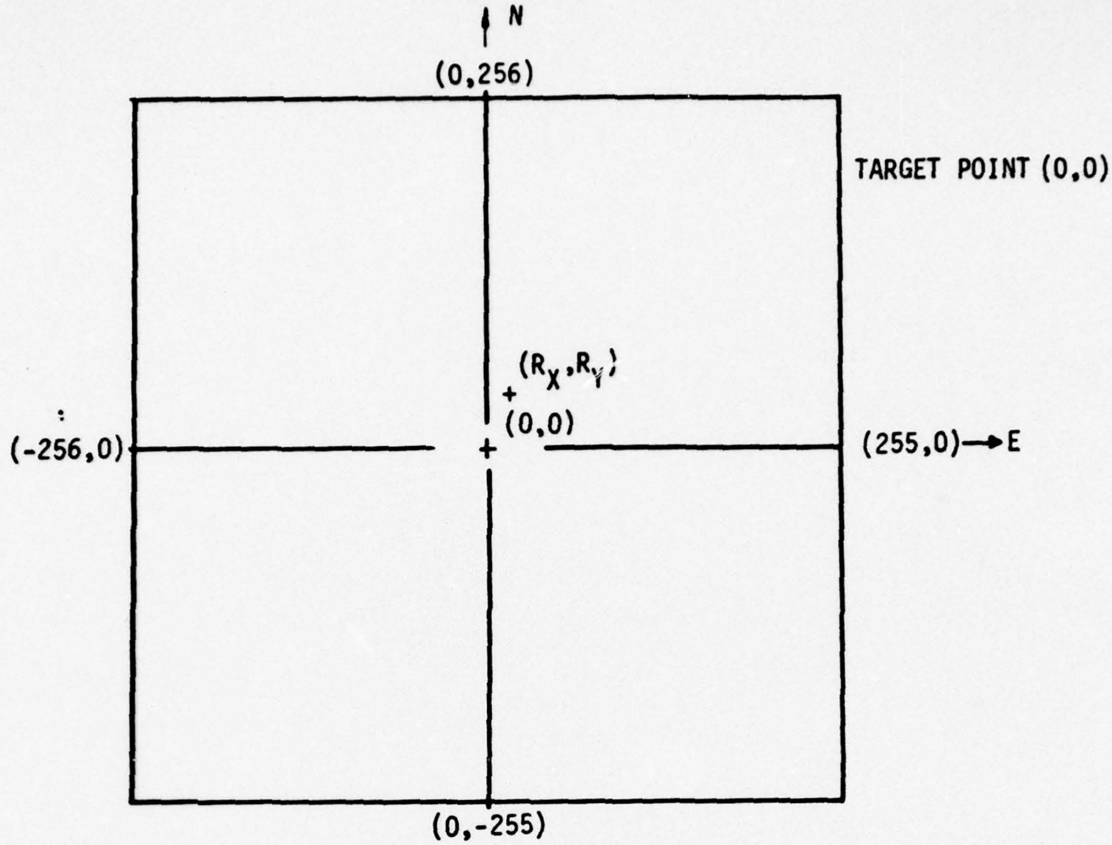



FIGURE 5. REFERENCE IMAGE

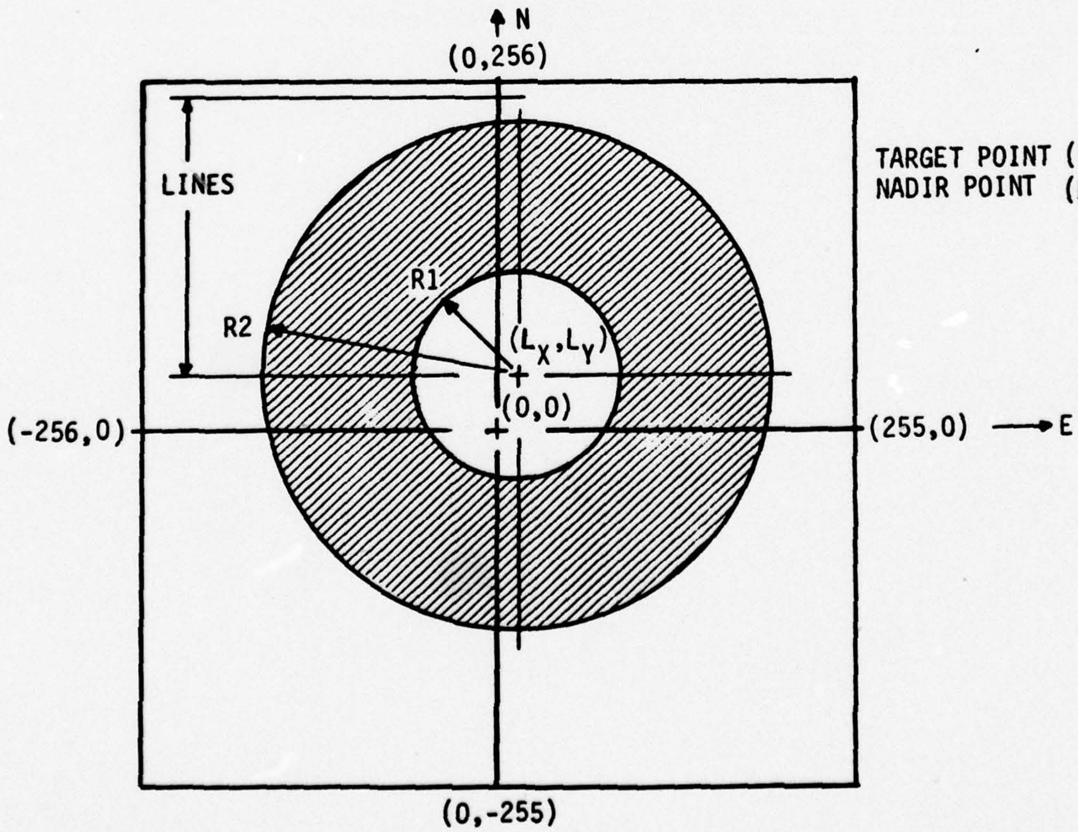



FIGURE 6. LIVE IMAGE

accepted in the RADAG mode. See Equation (7) in the previous section.

Figure 7 shows entries that change $R_2$, LINES and AXIS followed by another summary. Parameters may be entered in any order and may be re-entered any number of times. They will remain constant from run-to-run until changed by the operator. The START command initiates the actual correlation, the results of which are shown in Figure 8. Note that each time GYPSC erases the TEKSCOPE screen, the ledger is reprinted at the top so that all of the pertinent information appears along with the correlation results.

Figure 8 also shows operator entries for width, offset, and curve number. The curve of correlation amplitude returned from the STARAN processor, shown in Figure 9A, contains information over a greater excursion than is typically of interest. The curve displayed on the TEKSCOPE is a subset of the total correlation curve as shown in Figure 9B. The subset is selected by the width and offset entries. The TEKSCOPE screen size limits the "WIDTH" entry to a maximum value of 54. This subset, or window, also describes the limits of the correlation curve over which numerical statistics of the correlation process are taken. The "CURVE NUMBER" entry describes which of five possible types of curves (as defined in the menu shown in Figure 4) are plotted on the TEKSCOPE. The statistics include the maximum, minimum, average, and standard deviation of the unnormalized correlation function, the aperture function, and the normalized correlation function (PSI). The statistics also include the minimum and maximum values of the first derivative of PSI (DPSI) and the second derivative of PSI (DDPSI), as well as the positions of the minimum and maximum values of PSI, DPSI, and DDPSI. The statistics are dependent on the window selected by the WIDTH and OFFSET but do not depend on the curve number entered.

Note that there is a local minimum near the center in the plot of the un-normalized correlation function (see Figure 8). The center of the plot is always denoted by a plus (+) sign. Figures 9A and 9B tie the center of the plot back to the origin of the reference image (Figure 5) positionally. As the two example images (GYLIVE and GYREF) are of opposite polarity, the local minimum indicates the lateral position at which the two images are most dissimilar. (This is also known as the quotient match point.) The minimum is only local because the un-normalized correlation function is scene dependent. If the operator responds to the question "SHALL I CONTINUE"? with a carriage return, as was done in Figure 8, GYPSC will give the operator the opportunity to re-enter the statistics without re-running the whole correlation program. Figure 10 shows the aperture function (curve number 2) for the same run. Looping back to the statistics again and entering curve number 3 yields a plot of the normalized correlation function PSI (Figure 11). Note that the minimum is much more pronounced because the gross scene dependencies have been removed in the normalization process. The strength of the match is indicated by the difference between the minimum and maximum values of PSI. The position of the match is indicated by the position of the minimum value of PSI which is reported as plus 1 pixel on an integer basis and as plus 0.28 pixel by a three point parabolic curve fit interpolator.

Figure 12 shows curve number 4, the first derivative of PSI, and

```
RUN   TYPE    AXIS   MODE                X -REFR- Y    X -LIVE- Y    R1 -APR- R2    SIZE  LAMBDA
  9   CROSS   HORI   LINEAR              0        0    0        0    0       150    150        2
                            $R2=135

                            $LINES=135

                            $BOTH

                            $SUMM

RUN   TYPE    AXIS   MODE                X -REFR- Y    X -LIVE- Y    R1 -APR- R2    SIZE  LAMBDA
  0   CROSS   BOTH   LINEAR              0        0    0        0    0       135    135        2
                            $START
```

Figure 7

```
GYPSC          04/29/77  11.08.19.
   STARAN/CDC6400 AREA CORRELATION
.....LIVE IMAGE..........GYLIVE

.....REFERENCE IMAGE.....GYREF

        RUN  TYPE   AXIS  MODE       X -REFR- Y    X -LIVE- Y    R1 -APR- R2   SIZE  LAMBDA
          1  CROSS  BOTH  LINEAR     0        0    0        0    0       135    135      2
                          .....HORIZONTAL CORRELATION STARTED.....

                  .....STATISTICS--ENTER THREE INTEGERS  WIDTH,OFFSET,CURVE NUMBER.....
                                  135,0,1

                       MINIMUM            MAXIMUM           AVERAGE        STD. DEV.
         CORRELATION   3990.00            5378.00           4588.31        414.307
            APERTURE   13397.0            17396.0           15419.6        1147.03
                 PSI   .278846            .309152           .297312        .788632E-02
                DPSI   -.234130E-02       .209153E-02
               DDPSI   -.319993E-03       .169355E-02

             POS PSI        1      .28    -35   -34.00
            POS DPSI               -2               3
           POS DDPSI                6               1
```

```
             .....SHALL I CONTINUE?(YES OR NO; LOOP ON CR ONLY).....
                    N
```

Figure 8

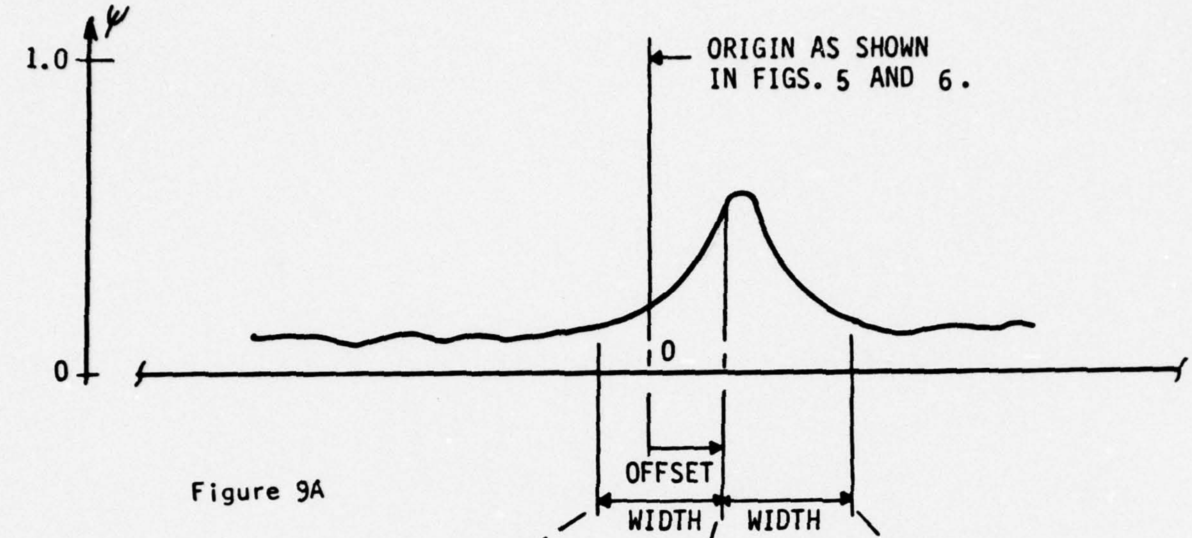



Figure 9A

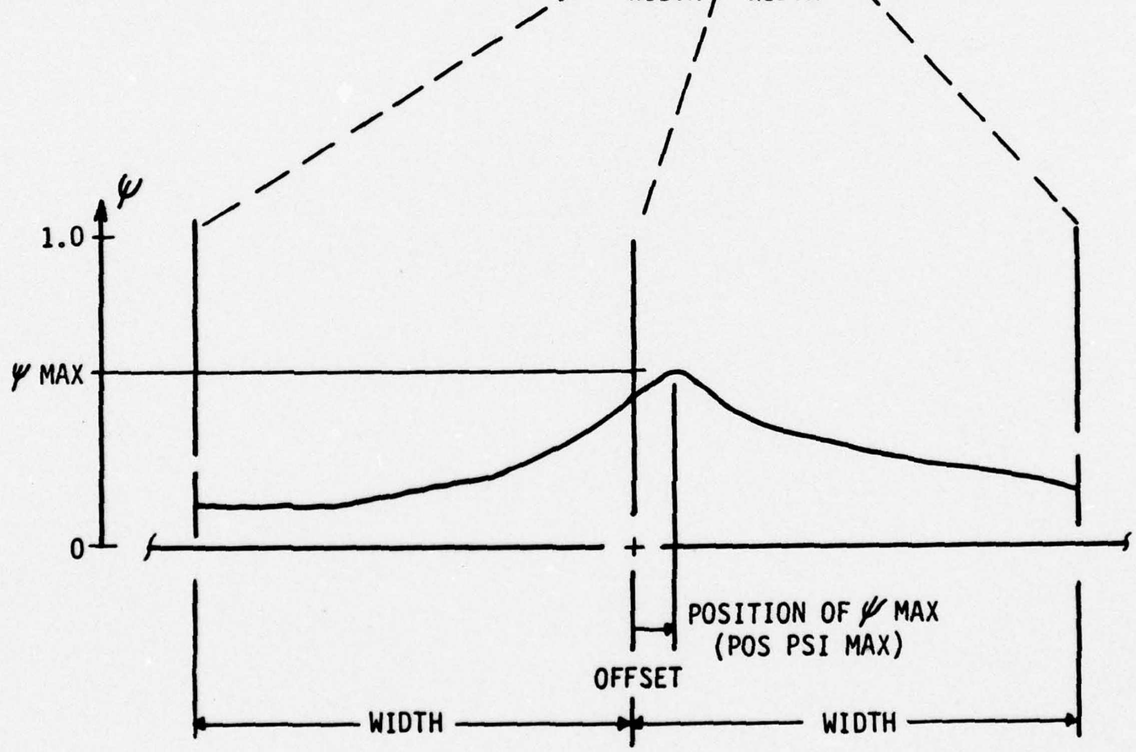



Figure 9B

CORRELATION AS A FUNCTION OF POSITION

```
GYPSC          04/29/77  11.10.06.
  STARAN/CDC6400 AREA CORRELATION
.....LIVE IMAGE..........GVLIVE

.....REFERENCE IMAGE.....GYREF


         RUN  TYPE   AXIS  MODE        X -REFR- Y    X -LIVE- Y    R1 -APR- R2   SIZE  LAMBDA
           1  CROSS  BOTH  LINEAR      0        0    0        0     0      135    135       2
                                 .....HORIZONTAL CORRELATION.....

                      .....STATISTICS--ENTER THREE INTEGERS  WIDTH,OFFSET,CURVE NUMBER.....
                                     *35,0,2

                       MINIMUM          MAXIMUM          AVERAGE       STD. DEV.
           CORRELATION 3990.00          5378.00          4588.31       414.307
              APERTURE 13397.0          17396.0          15419.6       1147.03
                   PSI .278846          .309152          .297312       .788632E-02
                  DPSI -.234130E-02     .209153E-02
                 DDPSI -.319993E-03     .169355E-02

               POS PSI      1      .28   -35   -34.00
              POS DPSI              -2             3
             POS DDPSI               6             1
```

```
                  .....SHALL I CONTINUE?(SYS OR SMS; LOOP ON CR ONLY).....
                        *
```

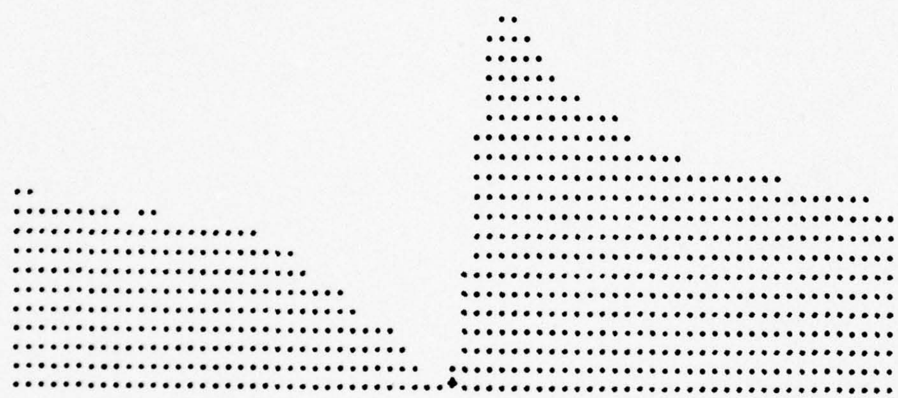
Figure 10

```
GYPSC          04/29/77  11.11.00.
   STARAN/CDC6400 AREA CORRELATION
.....LIVE IMAGE..........GYLIVE

.....REFERENCE IMAGE.....GYREF

      RUN  TYPE   AXIS  MODE       X -REFR- Y    X -LIVE- Y    R1 -APR- R2   SIZE  LAMBDA
        1  CROSS  BOTH  LINEAR     0        0    0        0    0       135   135        8
                              .....HORIZONTAL CORRELATION.....

                 .....STATISTICS--ENTER THREE INTEGERS  WIDTH,OFFSET,CURVE NUMBER.....
                              135,0,3

                   MINIMUM          MAXIMUM          AVERAGE          STD. DEV.
      CORRELATION  3990.00          5378.00          4588.31          414.307
         APERTURE  13397.0          17396.0          15419.6          1147.03
              PSI  .278846          .309152          .297312          .788632E-02
             DPSI  -.234130E-02     .209153E-02
            DDPSI  -.319993E-03     .168355E-02

          POS PSI       1      .28    -35   -34.00
         POS DPSI               -2              3
        POS DDPSI                6              1
```

```
.....SHALL I CONTINUE?(SYS OR SNS; LOOP ON CR ONLY).....
```

Figure 11

```
GYPSC          04/29/77  11.11.39.
STARAN/CDC6400 AREA CORRELATION
.....LIVE IMAGE..........GVLIVE

.....REFERENCE IMAGE.....GVREF

RUN  TYPE   AXIS  MODE       X -REFR- Y    X -LIVE- Y    R1 -APR- R2   SIZE  LAMBDA
  1  CROSS  BOTH  LINEAR     0        0    0        0    0       135    135      2
                       .....HORIZONTAL CORRELATION.....

         .....STATISTICS--ENTER THREE INTEGERS  WIDTH,OFFSET,CURVE NUMBER.....
                       *35,0,4

              MINIMUM         MAXIMUM       AVERAGE     STD. DEV.
CORRELATION   3990.00         5378.00       4588.31     414.307
   APERTURE   13397.0         17396.0       15419.6     1147.03
        PSI   .278846         .309152       .297312     .788632E-02
       DPSI   -.234130E-02    .209153E-02
      DDPSI   -.319993E-03    .169355E-02

    POS PSI      1     .28    -35   -34.00
   POS DPSI             -2               3
  POS DDPSI              6               1
```



```
.....SHALL I CONTINUE?(*Y* OR *N*; LOOP ON CR ONLY).....
*
```

Figure 12

Figure 13 shows curve number 5, the second derivative of PSI. Figure 14 shows the plot of PSI obtained by entering an offset other than zero while Figure 15 shows PSI with a larger width. Note that the statistics reported in these last two figures have changed because the size and position of the window have changed. The window may be enlarged to show the activity on the skirts of the curve, or restricted to confine the statistics to a local area of the curve. At the bottom of Figure 15 the operator entered "Y" to continue instead of looping back to re-enter the statistics.

Figure 16 shows the vertical normalized correlation curve of the same run. The operator may, at the bottom, enter a carriage return to loop back and re-enter the statistics. However the entry of a "Y" or a "N" will take him back to the top of the GYPSC program because Run 1 is complete.

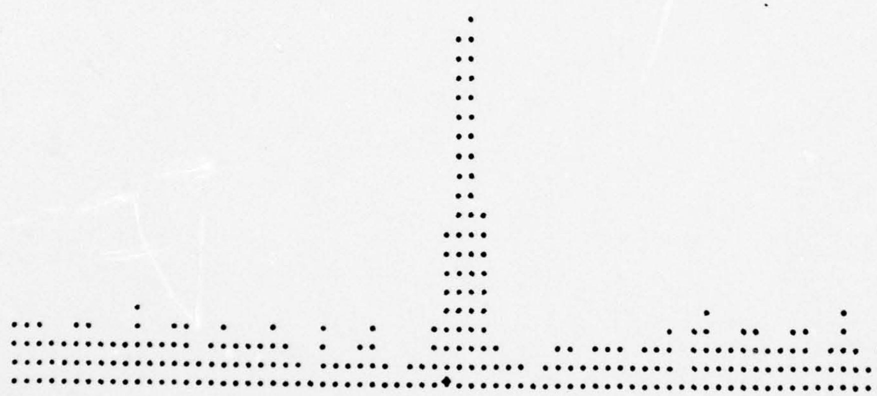
Figure 17 shows the beginning of the GYPSC program. Since GYPSC knows that it has already been run once, it gives the operator the option of terminating completely, using the images already inserted, or respecifying the images. In this example the operator chose the latter. By entering "A1" for COMTAL A or "B1" for COMTAL B, either image already existent on either COMTAL may be used for the live image, or for the reference image. This example then shows that GYPSC was directed to run an auto-correlation in the horizontal direction only and to give a summary of the parameters before actually starting the run.

Because an auto-correlation is a correlation of a portion of the reference image against the whole reference image, the resultant normalized correlation function as shown in Figure 18 gives a peak at the position of best correlation, plus 0.12 pixels in this example.

Figure 19 directs a RADAG cross-correlation. The results shown in Figure 20 are interpreted the same way as the linear mode except that additional statistics about the live scene are given. AVEL is the average value of the original live scene pixels that are within the aperture. SIGMA is an estimate of the standard deviation of these live scene pixels. RMAXL equals AVEL + (LAMBDA·SIGMA). RMINL equals AVEL - (LAMBDA·SIGMA). LMIN is the minimum value of these live scene pixels and LMAX is the maximum value of these live scene pixels.

Figure 21 shows how the proper parameters are taken from the header information encoded on tapes of live radar imagery generated on the Goodyear Aerospace radar re-sampler system. The normal use of the GYPSC program is to correlate a re-sampled live radar image against a reference image. Because an appropriate pair of resampled live and reference images were not available in DIAL image format when these documentation runs were made, two re-sampled live images were used, (PPIGY1) and (PPIGY2). These two images were taken on the same run of the same flight but differ slightly in altitude. See Table I for definitions of the legends used in live radar image headers.

```
GYPSC          04/29/77  11.12.25.
  STARAN/CDC6400 AREA CORRELATION
.....LIVE IMAGE..........GYLIVE

.....REFERENCE IMAGE.....GYREF

RUN  TYPE   AXIS  MODE        X -REFR- Y    X -LIVE- Y    R1 -APR- R2   SIZE  LAMBDA
  1  CROSS  BOTH  LINEAR      0        0    0        0     0      135    135       2

                     .....HORIZONTAL CORRELATION.....

        .....STATISTICS--ENTER THREE INTEGERS  WIDTH,OFFSET,CURVE NUMBER.....
                     $35,0,5

                 MINIMUM          MAXIMUM         AVERAGE       STD. DEV.
CORRELATION      3990.00          5378.00         4588.31       414.307
   APERTURE      13397.0          17396.0         15419.6       1147.03
        PSI      .278846          .309152         .297312       .788632E-02
       DPSI     -.234130E-02      .209153E-02
      DDPSI     -.319993E-03      .169355E-02

    POS PSI        1      .28     -35   -34.00
   POS DPSI                -2                3
  POS DDPSI                 6                1
```



```
         .....SHALL I CONTINUE?($Y$ OR $N$; LOOP ON CR ONLY).....
                  $
```

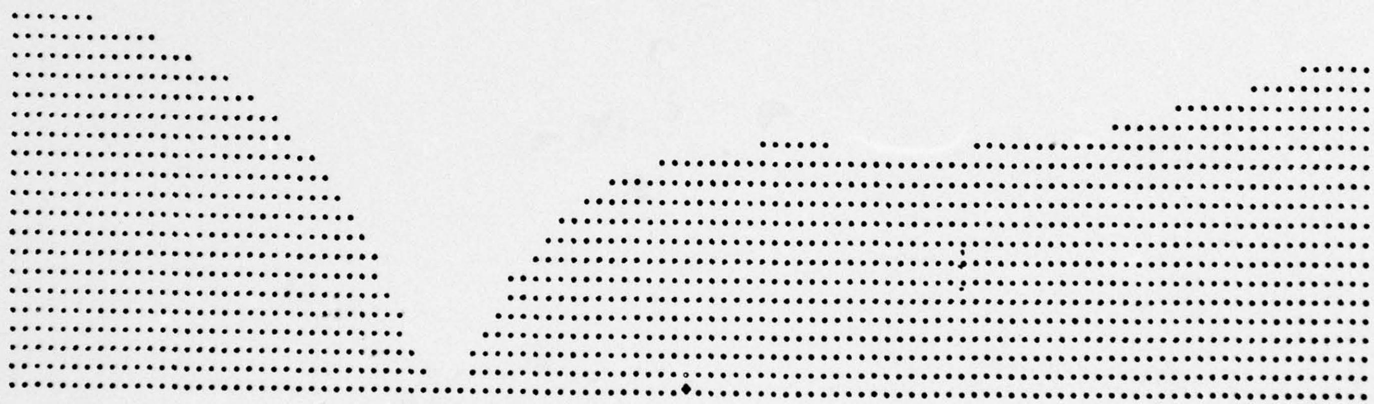
Figure 13

```
GYPSC          04/29/77  11.13.42.
STARAN/CDC6400 AREA CORRELATION
.....LIVE IMAGE..........GYLIVE

.....REFERENCE IMAGE.....GYREF

RUN  TYPE   AXIS  MODE        X -REFR- Y    X -LIVE- Y    R1 -APR- R2    SIZE  LAMBDA
  1  CROSS  BOTH  LINEAR      0        0    0        0    0       135     135       2
                    .....HORIZONTAL CORRELATION.....

        .....STATISTICS--ENTER THREE INTEGERS  WIDTH,OFFSET,CURVE NUMBER.....
                        $35,20,3

              MINIMUM          MAXIMUM          AVERAGE       STD. DEV.
CORRELATION   3654.00          4898.00          4208.34       321.358
   APERTURE   12168.0          16227.0          14271.8       1201.64
        PSI   .278846          .301843          .295127       .575574E-02
       DPSI   -.234130E-02     .209153E-02
      DDPSI   -.319993E-03     .169355E-02

    POS PSI   -19   -19.72     -35    62.12
   POS DPSI         -22               -17
  POS DDPSI         -14               -19
```

```
        .....SHALL I CONTINUE?($Y$ OR $N$; LOOP ON CR ONLY).....
                 $
```

Figure 14

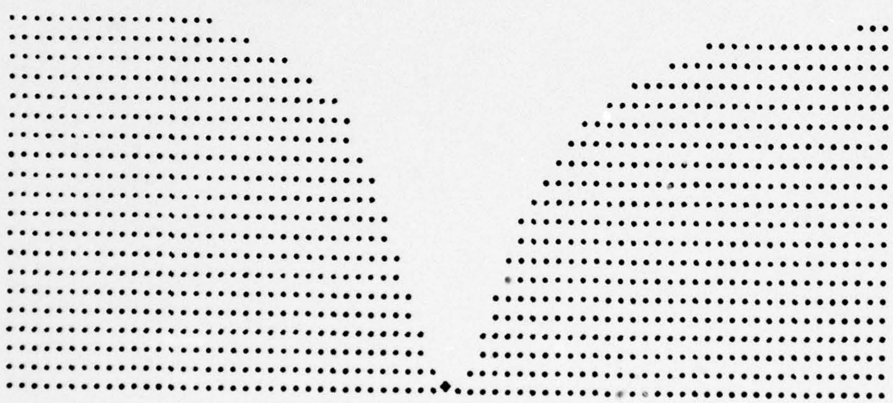
```
GYPSC          04/29/77  11.14.58.
STARAN/CDC6400 AREA CORRELATION
.....LIVE IMAGE..........GVLIVE

.....REFERENCE IMAGE.....GVREF

RUN  TYPE   AXIS  MODE      X -REFR- Y    X -LIVE- Y    R1 -APR- R2   SIZE  LAMBDA
 1   CROSS  BOTH  LINEAR    0        0    0        0    0       135   135        2
                  .....HORIZONTAL CORRELATION.....

        .....STATISTICS--ENTER THREE INTEGERS  WIDTH,OFFSET,CURVE NUMBER.....
                          $54,20,3

               MINIMUM          MAXIMUM          AVERAGE     STD. DEV.
CORRELATION    3422.00          5357.00          4253.12     551.396
   APERTURE    11206.0          17339.0          14252.2     1816.43
        PSI    .278846          .308957          .298489     .668660E-02
       DPSI    -.234130E-02     .209153E-02
      DDPSI    -.319993E-03     .169355E-02

    POS PSI    -19   -19.72     -54   -48.11
   POS DPSI          -22              -17
  POS DDPSI          -14              -19
```



```
.....SHALL I CONTINUE?($Y$ OR $N$; LOOP ON CR ONLY).....
     $Y
```

Figure 15

```
GYPSC            04/29/77  11.16.45.
STARAN/CDC6400 AREA CORRELATION
.....LIVE IMAGE..........GVLIVE

.....REFERENCE IMAGE.....GYREF

RUN  TYPE   AXIS  MODE      X -REFR- Y    X -LIVE- Y    R1 -APR- R2   SIZE  LAMBDA
  1  CROSS  BOTH  LINEAR    0        0    0        0    0       135    135       2
                    .....VERTICAL CORRELATION STARTED.....

          .....STATISTICS--ENTER THREE INTEGERS  WIDTH,OFFSET,CURVE NUMBER.....
                      135,0,3

               MINIMUM           MAXIMUM          AVERAGE      STD. DEV.
 CORRELATION   4310.00           4722.00          4595.85      105.444
    APERTURE   15328.0           15658.0          15468.0      70.0734
         PSI   .279073           .302584          .297097      .650699E-02
        DPSI   -.259595E-02      .231855E-02
       DDPSI   -.407310E-03      .160089E-02

     POS PSI   1     .01         -35   -34.00
    POS DPSI          -3                   4
   POS DDPSI           6                   1
```



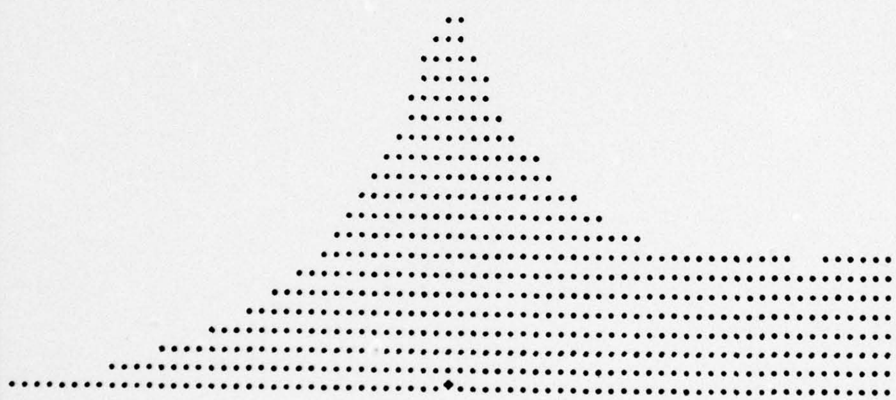
```
.....SHALL I CONTINUE?($Y$ OR $N$; LOOP ON CR ONLY).....
                 $N
```

Figure 16

```
        GYPSC          04/29/77  11.25.26.
    STARAN/CDC6400 AREA CORRELATION
                 .....TOP OF PROGRAM  Y=SELECT IMAGES, N=TERMINATE, CR=SAVE IMAGES.....

                      .....SHALL I CONTINUE?($Y$ OR $N$; LOOP ON CR ONLY).....
                                 $Y
ENTER DATA SET NAME FOR $LIVE$ IMAGE.   0 A1

IMAGE OVERLAY ON DISPLAY A1  IS- GYLIVE
ENTER DATA SET NAME FOR $REFR$ IMAGE.   0 B1

IMAGE/OVERLAY ON DISPLAY B1  IS- GYREF
.....LIVE IMAGE..........GYLIVE

.....REFERENCE IMAGE.....GYREF


                  .....ENTER PARAMETERS AND DIRECTIVES-($MENU$ FOR MENU LISTING).....
                                 $HORI

                                 $AUTO

                                 $SUMM

       RUN   TYPE    AXIS    MODE        X -REFR- Y     X -LIVE- Y     R1 -APR- R2    SIZE  LAMBDA
        1    AUTO    HORI    LINEAR      0        0     0        0     0       135    135        2
                                   $START
```

Figure 17

```
GYPSC          04/29/77  11.27.40.
STARAN/CDC6400 AREA CORRELATION
.....LIVE IMAGE..........GVLIVE
.....REFERENCE IMAGE.....GVREF

RUN  TYPE  AXIS  MODE     X -REFR- Y   X -LIVE- Y   R1 -APR- R2   SIZE  LAMBDA
  2  AUTO  HORI  LINEAR   0        0   0        0   0       135   135        2

                 .....HORIZONTAL CORRELATION STARTED.....

       .....STATISTICS--ENTER THREE INTEGERS  WIDTH,OFFSET,CURVE NUMBER.....
                          $135,0,3

               MINIMUM          MAXIMUM          AVERAGE      STD. DEV.
  CORRELATION  4046.00          5052.00          4652.25      309.253
     APERTURE  7970.00          10349.0          9173.49      682.396
          PSI  .488163          .539608          .507559      .128401E-01
         DPSI  -.374412E-02     .438264E-02
        DDPSI  -.548882E-02     .530776E-03

      POS PSI  -35   -34.00     0          .12
     POS DPSI              2               -2
    POS DDPSI              0              -13
```



```
          .....SHALL I CONTINUE?($Y$ OR $N$; LOOP ON CR ONLY).....
                    $N
```

Figure 18

```
     GYPSC          04/29/77  11.29.44.
STARAN/CDC6400 AREA CORRELATION
              .....TOP OF PROGRAM  Y-SELECT IMAGES, N-TERMINATE, CR-SAVE IMAGES.....
                   .....SHALL I CONTINUE?($Y$ OR $N$; LOOP ON CR ONLY).....
                               $

               .....ENTER PARAMETERS AND DIRECTIVES-($MENU$ FOR MENU LISTING).....
                               $CROSS

                               $RADAG

                               $SUMM

     RUN   TYPE    AXIS    MODE         X -REFR- Y      X -LIVE- Y      R1 -APR- R2    SIZE  LAMBDA
       2   CROSS   HORI    RADAG        0        0      0        0      0       135     135       2
                                   $START
```

Figure 19

```
     GYPSC          04/29/77  11.31.08.
  STARAN/CDC6400 AREA CORRELATION
.....LIVE IMAGE..........GYLIVE

.....REFERENCE IMAGE.....GVREF

         RUN   TYPE   AXIS   MODE          X -REFR- Y      X -LIVE- Y     R1 -APR- R2    SIZE  LAMBDA
           3   CROSS  HORI   RADAG         0        0      0        0      0      135    135       2

                        AVEL     SIGMA    RMAXL     RMINL        LMIN       LMAX    LAMBDA
                     78.4382   26.6867  131.8117   25.0648         28        237         2

                              .....HORIZONTAL CORRELATION STARTED.....

                    .....STATISTICS--ENTER THREE INTEGERS  WIDTH,OFFSET,CURVE NUMBER.....
                                   *35,0,3

                      MINIMUM          MAXIMUM          AVERAGE          STD. DEV.
        CORRELATION   2649.00          3634.00          3045.17          303.866
           APERTURE   6034.00          7835.00          6944.85          516.646
                PSI   .397519          .463816          .437930          .172099E-01
               DPSI   -.521265E-02     .460935E-02
              DDPSI   -.662182E-03     .396151E-02

            POS PSI      1       .32     -35   -34.00
            POS DPSI              -2                3
           POS DDPSI              14                1
```

```
                    .....SHALL I CONTINUE?(*Y* OR *N*; LOOP ON CR ONLY).....
                                   *N
```

Figure 20

```
     GYPSC          04/29/77  11.31.53.
  STARAN/CDC6400 AREA CORRELATION
          .....TOP OF PROGRAM  Y•SELECT IMAGES, N•TERMINATE, CR•SAVE IMAGES.....
               .....SHALL I CONTINUE?($Y$ OR $N$; LOOP ON CR ONLY).....
                    $Y
ENTER DATA SET NAME FOR $LIVE$ IMAGE.   @ PPIGY1
ENTER DATA SET NAME FOR $REFR$ IMAGE.   @ PPIGY2
.....LIVE IMAGE..........PPIGY1
                                        FLT•74  RUN• 2 CPI•13 UT 22 51 MAR 25,'77 PR 23 38 MAR 25,'77 FLT-TIME•02400040
                                        CPII•13 CPIF•20 AI•4906 AF•4792 NI• -978 NF• -901 EI• -982 EF•-1002 ANGI•125 B•3
.....REFERENCE IMAGE.....PPIGY2
                                        FLT•74  RUN• 2 CPI•14 UT 22 51 MAR 25,'77 PR 23 38 MAR 25,'77 FLT-TIME•02400040
                                        CPII•13 CPIF•20 AI•4638 AF•4519 NI• -818 NF• -741 EI•-1046 EF•-1065 ANGI•185 B•3
             .....ENTER PARAMETERS AND DIRECTIVES-($MENU$ FOR MENU LISTING).....
                                        $LX•-14
                                        $LY•-14
                                        $RX•-12
                                        $RY•-15
                                        $LINEAR
                                        $SUMM
     RUN   TYPE   AXIS   MODE           X -REFR- Y      X -LIVE- Y     R1 -APR- R2    SIZE  LAMBDA
       3   CROSS  HORI   LINEAR        -12      -15    -14      -14     0       135    135      2
                                 $START
```

Figure 21

TABLE I. RADAR IMAGE HEADER LEGENDS

| IMAGE HEADER | LEGEND |
|---|---|
| FLT | Flight number |
| RUN | Run number |
| CPI | Checkpoint initiation |
| VT | Time and date when the video tape was digitized |
| PR | Time and date when the digitized image was converted from polar to rectangular coordinates |
| FLT TIME | IRIG standard time off of the video tape |
| CPII | Initial CPI |
| CPIF | Final CPI |
| AI | Initial altitude (meters A.G.L.) |
| AF | Final altitude (meters A.G.L.) |
| NI | Initial position of nadir point north of the target (meters) |
| NF | Final position of nadir point north of the target (meters) |
| EI | Initial position of nadir point east of the target (meters) |
| EF | Final position of nadir point east of the target (meters) |
| ANGI | Initial azimuth angle (degrees w.r.t. true north) of the antenna when CPI started |
| B | Band number |

$L_x$ is obtained by divding east initial (EI) by the scale factor (in meters/pixel). $L_y$ is obtained by dividing north initial (NI) by the scale factor. The scale factor will be a constant for each band and should be requested when re-sampled live images are obtained.

$R_x$ and $R_y$ can initially be made the same as $L_x$ and $L_y$, respectively. If an initial vertical correlation shows an appreciable positional error, $R_y$ can be adjusted correspondingly for a subsequent horizontal correlation to obtain a stronger horizontal correlation peak. Conversely, if an initial horizontal correlation shows an appreciable position error, $R_x$ can be adjusted correspondingly for a stronger vertical correlation peak.

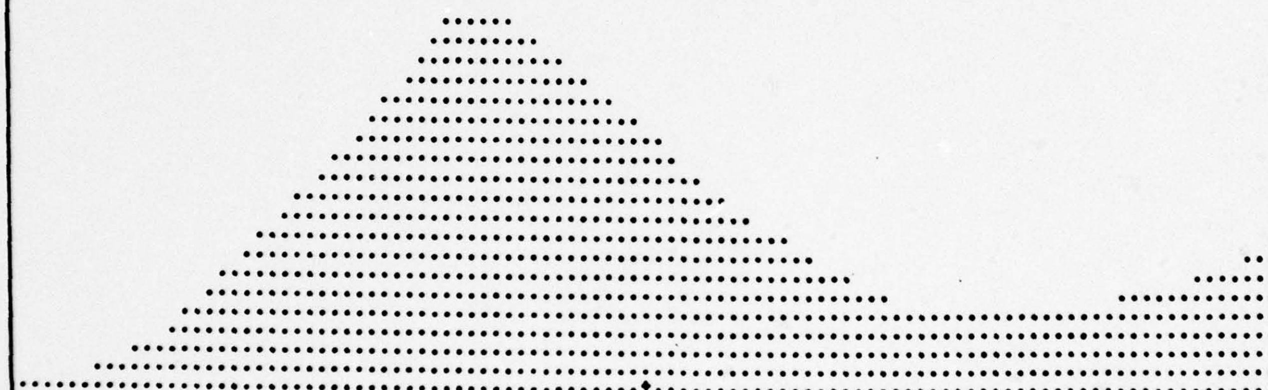
The PSI curves generated by GYPSC for horizontal and vertical correlations can be thought of as cuts through the correlation surface.

Note that due to the nature of a digital correlation program such as GYPSC, $L_x$ and $L_y$ can only be integer numbers. Additional positional accuracy may be obtained by modifying the correlation position reported by GYPSC by the *remainders* obtained from dividing EI and NI by the scale factor.

Figure 22 reports that the portion of live image PPIGY1 centered at $X = -14, (L_x)$, correlates best at position $X = -13.91$, ((POS PSI MAX)-OFFSET), in the reference image PPIGY2.

Figure 23 shows one method of *terminating* the GYPSC program. The other method is to enter "DONE" when GYPSC is requesting commands and directives.

```
GYPSC          04/29/77  11.36.17.
STARAN/CDC6400 AREA CORRELATION
.....LIVE IMAGE..........PPIGV1
                           FLT-74  RUN- 2 CPI-13 VT 22 51 MAR 25,'77 PR 23 38 MAR 25,'77 FLT-TIME-02400040
                           CPII-13 CPIF-20 AI-4906 AF-4792 MI- -978 MF- -901 EI- -982 EF--1002 AMGI-125 B-3
.....REFERENCE IMAGE.....PPIGV2
                           FLT-74  RUN- 2 CPI-14 VT 22 51 MAR 25,'77 PR 23 38 MAR 25,'77 FLT-TIME-02400040
                           CPII-13 CPIF-20 AI-4638 AF-4519 MI- -818 MF- -741 EI--1046 EF--1065 AMGI-185 B-3

     RUN   TYPE    AXIS   MODE          X -REFR- Y      X -LIVE- Y      R1 -APR- R2    SIZE  LAMBDA
       4   CROSS   HORI   LINEAR      -12       -15   -14       -14       0      135    135       2

                          .....HORIZONTAL CORRELATION STARTED.....

                  .....STATISTICS--ENTER THREE INTEGERS  WIDTH,OFFSET,CURVE NUMBER.....
                                  350,0.3

                     MINIMUM          MAXIMUM          AVERAGE      STD. DEV.
     CORRELATION     2264.00          4088.00          3336.76      550.122
        APERTURE     8378.00          14599.0          12303.7      1880.46
             PSI     .263206          .280698          .270738      .485432E-02
            DPSI     -.554581E-03     .775818E-03
           DDPSI     -.365295E-03     .199966E-03

         POS PSI     -50   -49.00     -14   -13.91
        POS DPSI                1              -20
       POS DDPSI              -14               45
```



```
                 .....SHALL I CONTINUE?(SYS OR SNS; LOOP ON CR ONLY).....
                          SN
```

Figure 22

```
      GYPSC        04/29/77  11.38.06.
  STARAN/CDC6400 AREA CORRELATION
             .....TOP OF PROGRAM  Y-SELECT IMAGES, N-TERMINATE, CR-SAVE IMAGES.....
                 .....SHALL I CONTINUE?($Y$ OR $N$; LOOP ON CR ONLY).....
                        $N
                       .....NORMAL CDC6400 TERMINATION.....
PM COMPLETE
```

Figure 23

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# REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

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| 1. REPORT NUMBER<br>ETL-0133 | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Correlation of digital images; Pershing II terminal guidance system simulation.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes a digital image area correlation computer program written for the U. S. Army Engineering Topographic Laboratories CDC-6400 and Staran computers. Its purpose is to predict the strength and positional registration of the correlation of two input images: (1) a live image taken from flight tests of the U. S. Army Pershing II missile terminal guidance system; (2) a reference image for use with the above guidance system.

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